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HIGHWAY CONCRETE (HWYCON) EXPERT SYSTEM IN THE CLASSROOM

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ABSTRACT: Expert Systems have proven to be useful tools to aid the decision-making process for the construction industry. HWYCON, a computer-based decision-support system was developed as part of the Strategic Highway Research Program's "Optimization of Highway Concrete Technology." The system was developed at the National Institute of Standards and Technology and is now being used by highway departments throughout the United States. Included in the HWYCON knowledge base is high-level expert knowledge, visual information (digitized photographs and drawings), and reference information for concrete pavements and structures. HWYCON was designed to address three materials-related activities: 1) distress identification and diagnosis, 2) selection of materials for construction and reconstruction, and 3) guidance on the use of materials and procedures for several repair methods. HWYCON has been used in the classroom in an upper-class/graduate course on durability of construction materials. The students used the HWYCON system to become familiar with materials selection issues. A homework assignment could easily be developed using HWYCON.

INTRODUCTION

This paper describes a computerized expert system that was developed for use by the highway industry. Due to the presence of high level (expert) technical knowledge contained in the system and its operating mode, the system can be used for the teaching of concrete technology in a classroom.

THE USE OF EXPERT SYSTEMS TO IMPROVE DECISION-MAKING

Expert systems can aid decision-making because they contain high-level knowledge about a subject area, often called a domain. For example, in the diagnostics area a domain can be small, such as a class of distresses that can occur in a concrete structure (e.g. cracking due to alkali-aggregate reactivity). A domain can also be large, such as all activities that relate to the diagnosis, construction, repair, and performance of a structure. Expert systems perform best when the knowledge domain is small and the knowledge-base is not dynamically changing.

Most expert systems are designed to mimic the role of an expert. The user or operator of the system is presumed to have a lesser knowledge or be familiar with the domain being investigated. A question-and-answer session is conducted, whereby the expert system concludes the session by providing the user with a hypothesis, conclusion, or recommendation. In some cases, the expert system may use probabilities to quantify the validity of a condition(s) or conclusion(s). Instructions are then given to perform

additional tests in order to confirm the hypothesis, or the system may suggest that an expert be consulted.

The benefits of expert systems can be many, assuming that careful thought is given in their purpose and design, users are included in the development process; and provisions are established for maintenance and enhancements. Table 1 lists three specific benefits of expert systems.

BACKGROUND AND DEVELOPMENT OF HWYCON

HWYCON was developed as part of the Strategic Highway Research Program's (SHRP) Project C-206 on "The Optimization of Highway Concrete Technology" (1). The system was developed by members of the Building Materials Division staff at the National Institute of Standards and Technology. HWYCON represents a two year effort that began in 1991 and was completed in 1993. Minor revisions were made in 1994. The principal goal of HWYCON was to interpret and represent the body of knowledge produced by other SHRP programs on concrete technology, and what was considered to be acceptable practice in the concrete industry. The system was designed to represent materials-related activities that involve the diagnosis, materials selection, and repair and rehabilitation of highway concrete structures. The development team for HWYCON consisted of three primary, high-level experts and a knowledge engineer, representing 100 years experience in concrete durability. In addition, twelve members of a SHRP Expert Task Group established guidelines, provided knowledge, and reviewed HWYCON. The task group members represented state DOT's, academia, and practicing engineers from the highway industry. Three prototype versions were generated and reviewed during the development of HWYCON. Representatives from twelve state DOT's were included in the review process. The design, development, and implementation of HWYCON required several phases. Figure 1 identifies the phases and their sequence.

HWYCON was developed using an expert system shell programming tool (2). The tool uses an object-oriented architecture. It is estimated that the use of this tool reduced the development time for computerizing the knowledge by about half.

KNOWLEDGE DOMAIN

Three major areas involving highway concrete structures are addressed by HWYCON. They include: 1) diagnostics - the identification and cause of materials-related distresses, 2) materials selection - recommendations on the selection of materials for construction and reconstruction, and 3) repair and rehabilitation - recommendations on the use of materials and procedures for various repair methods. Table 2 shows the specific knowledge contained in each of the three HWYCON sub-systems and the intended user of each sub-system. Various sources of knowledge are included in the knowledge base. To the extent possible, results of SHRP research programs were included. Examples include the "Distress Identification Manual for the Long-Term Pavement Performance Studies"

(3), the SHRP alkali-silica field test (4), and high-performance (fast track) concrete (5). In order to make the system comprehensive, it was necessary to use additional sources of knowledge. For example, the sub-system dealing with materials selection is based primarily, on the American Concrete Institute Committee 201, "Guide to Concrete Durability" (6). However, HWYCON knowledge extends beyond the scope of the Committee 201 guide. Additional knowledge from Federal Highway Administration (FHWA) projects, and state DOT's are represented in advanced methods for recycling concrete and permeable bases. Finally, the repair and rehabilitation sub-system contains knowledge represented in guides and accepted practice from SHRP, the American Association of State Highway Transportation Officials (AASHTO), and the American Concrete Pavement Association. The repair and rehabilitation sub-system presumes that the selection of the repair method (e.g. bonded overlays) has already been made. Also, this sub-system deals only with concrete pavements.

Use of Multiple Knowledge Formats HWYCON knowledge is represented in several different formats. These include:

- high-level reasoning from experts (facts and rules-of-thumb)
- visual information (digitized photographs and drawings)
- bibliographic references
- explanatory statements

HWYCON knowledge is presented to the user on a computer screen. The system uses a graphical interface where the various forms of knowledge are represented in one or many screen displays. The integration of the various knowledge forms is seamless to the user. The user operates the system through the use of a pointing device and push buttons. For example, a session consists of a series of question-and-answer screen displays. A typical screen display includes; a question, a set of possible responses, push buttons for viewing visual, explanatory, or bibliographic information, and an "enter" push button that directs the system to proceed to the next step (question or goal). The system attempts to find a goal (conclusion or recommendation) based on the responses to the questions. When a goal is reached, a screen display is presented to the user. Conclusions, recommendations, and additional information is available in this screen. The user also has option of restarting, repeating the session, continuing or exiting the sub-system.

REQUIREMENTS FOR USING HWYCON

HWYCON is designed to operate on a MS-DOS with Windows 3.1, personal computer. The computer resource requirements are shown in Figure 2. In addition to computer requirements, information about the structure is necessary. For example, to diagnose distresses in concrete pavements, the user should be prepared to answer the following types of questions:

- What is the type of concrete pavement (jointed, plain or continuously reinforced)?

- What is the type of distress observed (cracking, surface, joint-related)?
- What is the orientation and pattern of the cracking (longitudinal, transverse, map cracking, etc.)?
- Is there a history of previous materials-related problems (sulfate attack)?
- Does the observed distress symptom look similar to the displayed photograph?

When a portable computer is used in the field, the user conducts a dialogue with the computer by comparing the structure's visual condition with the information provided on the computer screen. The use of a desktop computer requires completing a written checklist that is provided in the HWYCON User's Guide.

HWYCON IMPLEMENTATION

SHRP has designated HWYCON as SHRP Product Number 2039. Version 4 of HWYCON is currently being distributed by the National Research Council, Transportation Research Board (TRB) (6). Provisions exist for the distribution of 3,000 copies. The distribution package includes the following components:

- One diskette containing the proprietary run-time engine
- Six diskettes containing the knowledge base
- SHRP-C-406 report (7).

State DOT's may receive HWYCON free of charge. The FHWA has established a "Durability Showcase" contract with the Construction Technology Laboratories of Skokie, Illinois, in which HWYCON is included as part of a series of workshops that will be presented to state DOT's, nationwide. In addition, local and county governments, academia, and highway consulting engineers are expected to purchase HWYCON for use in their organizations. Considerable interest in HWYCON has been expressed by colleges and universities. The system is expected to perform a tutorial role in the teaching of concrete knowledge to future practitioners.

USE OF HWYCON IN THE CLASSROOM

HWYCON was recently used in a Civil Engineering course at the University of Illinois. The class was an upper-level graduate course on durability of construction materials. Enrollment is low, typically 5 to 10 students. Students were required to have taken an undergraduate course on behavior of materials, and most students had also taken a course on properties and behavior of concrete. The course covers the full range of construction materials -- steel, concrete, and polymers. It focuses on the fundamental nature of deterioration of each material, the electrochemistry responsible for steel corrosion, the chemistry and physical chemistry behind concrete deterioration, and the chemistry involved in degradation of polymeric materials. The course also aims to relate these various fundamentals to practical aspects of deterioration, so throughout the course

students discuss issues such as materials selection and the influence of design on durability.

Using HWYCON in this course; illustrates key features of concrete durability, and it demonstrates how expert systems can be used for the selection of construction materials. The basis for the various decisions and recommendations of the program can be discussed in light of the knowledge already gained by the students. It utilizes a more interactive format to supplement traditional lectures on concrete deterioration. And it emphasizes engineering aspects of materials deterioration, an important objective throughout the course. Computer programs, especially programs that incorporate visual information, can enhance student learning in a way that even the most inspired lecture often does not. Expert systems are a powerful new tool in materials engineering, and their demonstration in a course such as this serves a useful purpose.

HWYCON'S FUTURE

Since the completion of HWYCON, new knowledge has been published by SHRP and other organizations in the concrete industry. In order for HWYCON to continue to be useful, it will be necessary to update the knowledge base and increase its operational capabilities. Currently, the ACI, NIST, and TRB are exploring ways of working together to ensure the increased capabilities of HWYCON in the future. It is hoped that an enhanced version will be available within two years. The new version is likely to include new knowledge on additional distresses, multimedia capabilities, and extend beyond highway pavements and bridges, to include hydraulic structures, parking garages, and other application of concrete.

CONCLUSIONS

This paper described the development, implementation, and use of an operational expert system HWYCON, for highway concrete structures.

1) HWYCON increases the decision-making capabilities of practicing inspectors and engineers, concrete specifiers, and decision-makers in the highway industry by providing current knowledge and high-level reasoning to problem-solving.

2) Due to the tutorial nature of the computer-based system, it is useful for teaching fundamental aspects of determining currently accepted methods and materials for construction and reconstruction, and repair and rehabilitation of highway concrete structures.

REFERENCES

1) Whiting, D., N. Nagi, T. Yu, D. Peshkin, K. Smith, M. Darter, J. Clifton, L. Kaetzel., "Optimization of Highway Concrete Technology," Report No. SHRP-C-373, Strategic Highway Research Program, National Research Council, Washington, DC 1994.

2) Level5 Research, "Level5 Object: Object-Oriented System for Microsoft Windows," Information Builders, New York, New York, 1993.

3) SHRP, "Distress Identification Manual for the Long-Term Pavement Performance Studies," Report No. SHRP-P-338, Strategic Highway Research Program, National Research Council, Washington, DC, 1993.

4) Stark, D., "Handbook for the Identification of Alkali-Silica Reactivity in Highway Structures," SHRP-C/FR-91-101, Strategic Highway Research Program, National Research Council, Washington, DC, 1991.

5) Leming, M. L., S. H. Ahmad, P. Zia, J. J. Schemmel, R. P. Elliott, A. E. Naaman, "High Performance Concretes", SHRP-C/WP-90-001, Strategic Highway Research Program, National Research Council, Washington, DC, 1990.

6) ACI Committee 201, "Guide to Durable Concrete," ACI 201.2R.77, American Concrete Institute, Detroit, MI, 1977.

7) Kaetzel, L. J., J. R. Clifton, K. S. Snyder and P. Klieger, "User's Guide to the Highway Concrete (HWYCON) Expert System," SHRP-C-406, Strategic Highway Research Program, National Research Council, Washington, DC, 1994.

Table 1 - Specific Benefits of Expert Systems

Benefit	Importance
Knowledge preservation	High-level experts leaving practice
Improved understanding of knowledge and decision-making process	Increased performance, service-life, and reduced costs
Knowledge integration	All forms of knowledge about a domain can be presented seamlessly to the user

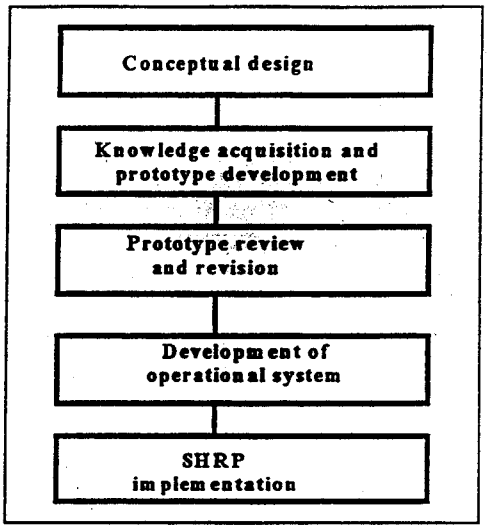

Figure 1 - HWYCON development phases.

Table 2 - HWYCON sub-systems and audience.

Sub-system Name	Knowledge	Intended User
Diagnostics: CONPAV-D CONSTRUC-D	• Concrete pavements • Bridge decks • Structures (columns, piers)	Inspectors and engineers
Materials selection: CONMAT	• Durability environments: - Corrosion of reinforcing steel - Freeze-thaw actions - Sulfate attack - Alkali-aggregate reactivity • Permeable bases • Recycling concrete • Fast track concrete (early opening, high-strength)	Concrete specifiers
Pavement Repair and rehabilitation: CONPAV-R	• Bonded and unbonded overlays • Full-depth and partial-depth repair • Diamond grinding and milling	Decision-makers

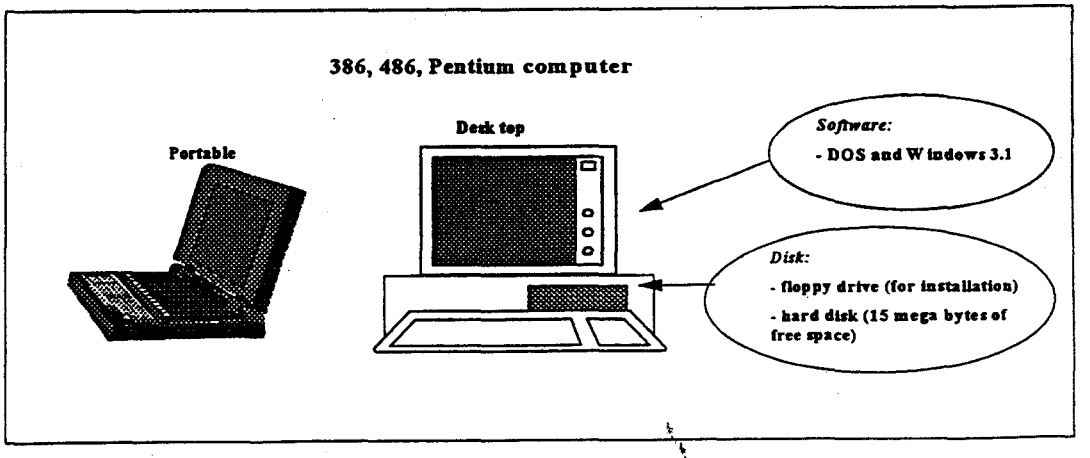

Figure 2 - Computer resource requirements